



This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

- + *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
- + *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
- + *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
- + *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at <http://books.google.com/>









ON THE
CONSTRUCTION OF CATCH-WATER RESERVOIRS
IN MOUNTAIN DISTRICTS.

IN designing a catchment reservoir which is intended to afford a supply of water, either to a town or for manufacturing purposes only, the principal subject which occupies the attention of the engineer engaged in the work, is the nature of the watershed or gathering ground from which the water is to be obtained.

ALTITUDE OF WATER SHED.

The first point to be considered is a very simple one, namely, whether the watershed proposed to be utilized, is situated at a sufficient altitude above the place to be supplied, and also above the highest point on the route, over which it is intended to convey the water, so that all deep cutting or lengthy tunnelling may be avoided as much as possible, while, at the same time, it must be borne in mind that the difference of level between the watershed and the destination of the water must not be so great as to cause the conduit, if an open one, to be laid with gradients so steep, that the velocity of the current will injure the stability of the channel ; or, if composed of pipes, of the pressure on them being too great to be resisted without

incurring great expense in casting the pipes of extraordinary thickness.

The question of excessive altitude can be met by the employment of balancing reservoirs on the pipe line, which will reduce the velocity or pressure to any desired extent, and this subject should be well considered in the original designs, instead of leaving the construction of the balancing reservoirs until the completion of the works, which has happened in the construction of very extensive undertakings.

But it is not proposed in the present work to enter into the question of the distribution of water.

AMOUNT OF RAINFALL.

The next point to be considered is the amount of rainfall on the watershed. Fortunately for the engineers of the present day, there is now a very much larger number of rain gauges, established in various parts of the country than there was twenty years ago, when the catchment system was first generally adopted for the supply of our principal towns. Consequently, engineers have now generally, tolerably reliable observations, on which to base their calculations, as to the average rainfall of the *district* in which the particular watershed, they are interested in, is situated. But the rainfall of a district, particularly among the hills, where catchment reservoirs are usually situated, is exceedingly variable, and therefore it is advisable to place as many gauges as possible on the watershed itself, and to continue to observe them for a lengthened period before reliable data can be obtained, on which to base the calculations, as to the probable amount of water that can be obtained.

GUAGES.

The gauges generally used, are of two descriptions, namely, "rain" and "stream." It is of the greatest importance that the former should be placed in such positions that they may receive a fair proportion of the rainfall, and neither more or less. They should be placed, if possible, in the open country, all gorges or escarpments being avoided. The altitude of the guages should also be accurately ascertained in order that they may be compared with the nearest standard guage, of which reliable observations have been taken for a number of years, and the proper allowance made for their relative levels; 3 per cent. of additional rainfall may be expected for every additional 100 feet of altitude.

Guages placed on the lee side of a hill or escarpment, *over* which the clouds can ride, will collect an abnormal quantity of water; as the rain clouds float over the hill, settle under the lee of it, and there precipitate the rain. On the other hand, when the hill is high enough to penetrate them, the weather side is the wettest, because being arrested and detained by the mountain, they deposit their moisture on the weather side. The average height of rain clouds in England varies from 1,000 feet to 1,500 feet above the sea level. Stream gauges are even, perhaps, of greater importance than rain guages if they are properly constructed, and carefully observed, as they show the actual amount of water, which flows off the watershed at a certain point, and the difference between the quantity of rain which falls on the whole of the watershed as calculated by means of the rain guages, and the volume of water passing through the stream gauges will show the amount which should be deducted from the rain

fall, in order to allow for evaporation and absorption. Members of the Institution of Civil Engineers are referred to a very valuable paper by Mr. Robert Manning, M. I. C. E., which was read on April 24th, 1866, and gives the result of some very interesting experiments on the flow of water off the ground.

Unless great care is taken with the stream gauges, serious errors may be made.

They should be so constructed as to admit of the greatest floods passing freely through them without interfering with the accuracy of the observations.

To ensure this result, they should be constructed of nearly the maximum width of the stream in order to prevent the water backing up above them, and at the same time the channel below the gauge should be carefully cleared from obstacles, and a rapid fall obtained in the bed of the stream, so as to ensure a clear vertical drop over the gauge for the water, and thus prevent it becoming what is called "a drowned gauge." Care should also be taken that the gauge is perfectly watertight, so that no water can pass round or under it without being observed.

NATURE OF WATERSHED.

A careful examination should be made of the watershed, in order to ascertain whether any artificial drainage operations lead the water away from its natural course, and if such drains or watercourses exist, the water conveyed by them must be added to the quantity which passes over the main stream gauge before calculating the loss by evaporation by comparing the rain and stream gauges.

The geological strata and inclination of the ground comprised in the watershed must be taken into consideration.

A rocky and precipitous formation is the most favourable from which to collect water.

From being impervious and from its steep gradients, the rain flows rapidly into the stream or reservoir, and is therefore less liable to be absorbed into the ground or evaporated by the heat of the sun than on a flat and permeable surface.

When the water is required for the supply of towns, purity is an essential element, and this is ensured by the absence of peaty or boggy ground, highly cultivated land, or obnoxious manufactories—limestone is also an objectionable formation for a gathering ground, because the water flowing from it, is hard and more or less impregnated with lime, in addition to which this formation frequently contains fissures capable of conveying away large rivers into unknown regions.

Numerous instances exist in the limestone districts of Yorkshire and Wales, of what are termed “swallows,” through which large bodies of water disappear, and in some cases it cannot be ascertained where they reappear on the surface.

The softer species of sandstone, especially the “New Red,” are also exceedingly absorbent.

In some formations there are beds of porous material lying under a tolerably watertight strata, which will convey the water away from the natural watershed of the rain into another district; and in other cases this is reversed, and the yield of the watershed is increased by rain brought from a far distant source.

In fact in order to obtain absolutely correct results, what may be termed the "hydraulic" watershed must be ascertained, as well as the mere natural one obtained on the surface by a contour line.

But practically this can rarely be done; at the same time, all possible information should be obtained as to the geological formation of the district, and as to the probability of water being conveyed away by subterranean channels.

AMOUNT OF RAINFALL WHICH CAN BE IMPOUNDED.

The calculation as to the amount of rainfall which can be impounded and utilized, is perhaps one of the most difficult questions which an engineer has to decide, and until recently there was an enormous disparity between the estimates of the most eminent members of the profession, and it cannot be said that any basis has yet been established on which this calculation should be made; hence the frequent parliamentary contests on water works bills and the terrific battles between the millowners and others interested in the water which it is proposed to abstract, and the company or corporation who want it.

It is a question worthy of consideration whether it would not be advisable to institute such enquiries as would establish reliable data on this subject, which might rank with the experiments on wrought and cast iron by Fairbairn, Hodgkinson, and others.

In the first instance, the rainfall must be ascertained from the nearest gauge which has been established for a lengthened period: observations should be obtained, if possible, extending over at least 20 years.

The results shown by this gauge should be compared with those placed on the watershed, and by a careful comparison of the relative quantities measured in each month by the temporary and standard gauges, and making a due allowance for their relative levels, a tolerably correct average annual rainfall may be obtained.

By comparing the quantity of water which should flow from the watershed, according to the ascertained average rainfall on the total area, and the quantities ascertained to pass through the stream gauges, the amount of loss due to evaporation and absorption will be ascertained.

But it is not always possible to make this deduction with anything like accuracy; again, no ordinary reservoirs can be made of sufficient capacity to store the heavy floods in an exceptionally wet year for use in an extremely dry season.

It is found that the wettest year in a series of twenty years, often has a rainfall one-third greater than the average annual amount for the whole period; on the other hand the rainfall of the driest year may be one-third less than the average, and these two extremes may have an interval of many years between them, thus rendering it practically impossible to store the maximum floods for use during the maximum droughts.

But two or three dry years often occur in succession, and it is these periods which test the supplying capabilities of the reservoir to the utmost extent, as frequently the rainfall during the winter is little more than sufficient to supply the daily quantity drawn from the reservoir, which is then half empty when the summer drought commences.

The wettest years, on the contrary, test the substantial

character of the works, and the sufficiency of the provision made for the discharge of surplus water.

In order to meet these difficulties it is the practice among some of the leading engineers to deduct one-sixth from the *average* rainfall to allow for floods which cannot be stored, and Mr. Hawkesley has adduced numerous tables which show that the subtraction of one-sixth from the average rainfall of 20 years gives the average annual rainfall of the three *dryest consecutive* years in that period ; while the deduction of one-third from the average gives the amount of rain in the single *dryest* year, and the addition of one-third that of the single wettest year.

Table No. 1, in the appendix, shows how nearly this calculation is correct, and it should be noticed that this result is most apparent where the rain gauges have been observed for the longest period.

Having then deducted one-sixth from the average rainfall, the amount due to absorption and evaporation has to be determined upon.

In this the engineer will be guided by the rain and stream gauges ; the strata and inclination of the ground, &c., which have already been discussed.

In England the amount due to evaporation and absorption varies from 9 to 19 inches per annum.

In ordinary mountain districts it may be assumed at 14 inches, but this varies in proportion to the rainfall.

Thus in dry years the loss of water under this head is greater in proportion to the amount of rain which falls than it is in wet ones, for in the former instance, supposing a long drought to have prevailed, the ground being dry, absorbs

nearly all the rain which falls upon it, perhaps in the form of light passing showers ; while in wet years the ground soon becomes surcharged with moisture, and the rain flows over the surface, and is easily impounded.

Mr. Manning, in the paper already alluded to, states that in one district, the loss or difference between the rainfall and the supply varied from 11·79 inches to 15·16 inches, the mean annual loss being 13·71 inches.

Sometimes the loss for evaporation is taken at 25 per cent. of the rainfall.

Having ascertained the average rainfall of the district and deducted one-sixth for water which cannot be impounded, also the amount lost by evaporation and absorption, we shall then have arrived at the probable amount of available rainfall.

PROPORTION OF RAINFALL DUE TO RIPARIAN OWNERS.

It then becomes necessary to determine the proportion of the *available* rainfall which is due to the riparian owners.

Formerly the average rainfall was taken after allowing for evaporation only, as the amount to be divided between the riparian owners and the impounders of the water, without deducting one-sixth for flood waters which go to waste ; and it is this error which is one of the principal causes of the partial failure of several large waterworks in this country, because in very dry years the amount fixed to be sent down the streams as compensation water has exceeded the quantity available for the owners of the reservoirs.

It is perfectly just that the deduction for floods should be

made before dividing the available water between the respective parties ; for had the riparian owners constructed reservoirs of their own, they would have lost the same quantity.

In some, but very few instances there are no owners, who will be injured by the abstraction of the water, or they may be so few in number that they can be compensated for their loss by money payments, to enable them to substitute steam for water power and other purposes.

Again in the densely populated districts of Lancashire and Yorkshire, the claims of these owners are a very serious consideration.

For it must not be forgotten that, by the standing orders of the House of Commons, notice of the intention to apply for power to abstract the water from any stream, must be served upon every owner or lessee of a mill or manufactory situated upon that stream within 20 miles below the point at which the water is to be abstracted, unless the stream shall unite with a navigable river in less than 20 miles, in which case, the notice need only be served as far as the junction of the two streams.

In impounding water it must be recollect that any stream which has a natural course, cannot be abstracted without compensating the landowners on the stream, *and* obtaining an Act of Parliament.

Underground water can be dealt with by the owner of the surface.

It has become a very common rule in the manufacturing districts to allow one-third of the available rainfall to the riparian owners, leaving two-thirds for the impounders.

In some instances this is varied to the proportion of one quarter to the former and three quarters to the latter.

DIMENSIONS AND CAPACITY OF RESERVOIR.

The dimensions and capacity of the reservoir are calculated, so as to impound sufficient water, to enable a constant fixed supply to be maintained during the longest period of drought.

In determining the average daily supply required for a town, the allowance varies from 20 gallons to 50 gallons per head, of the population, the amount being differently estimated by engineers, and generally depends upon the proportion of manufactories in the district to be supplied.

Twenty gallons per head, per diem may be considered the minimum allowance for ordinary country towns, and rural districts, and 40 gallons for large towns possessing a fair proportion of manufactories.

In both these cases the allowance includes the necessary quantity of water for flushing sewers, watering streets, and other public purposes.

In constructing impounding reservoirs for manufacturing purposes, or for equalizing the flow of the rivers, other considerations are brought into action, as to the daily quantity required.

The amount of storage room required must vary in different parts of the country, and diligent enquiries should be made, in order to ascertain the actual longest period of dry weather ever registered.

The reservoir should be capable of containing from 150 to 200 days' supply, for though droughts for such periods, are almost unknown in England, still it must be borne in mind

that a drought may commence when the reservoir is only half full, owing to a previous deficiency of rainfall.

It is usually calculated that except at the end of a prolonged dry season, there is, even in fine weather a flow of one-fourth of a cube foot per second from each 1000 acres of the watershed, but as small a quantity as 11 cube feet per minute=0.183 cube feet per second has been registered. This gives a flow of 100,000 gallons in 24 hours.

Mr. Bateman, in his evidence before the royal commission on the supply of water to the metropolis, stated that the longest drought ever experienced on the Manchester water works lasted for 105 days.

In his scheme for supplying London with water from Wales, he provides storage accommodation for 120 or 140 day's supply.

Table No. 1 in the appendix gives a variety of statistics relative to the annual and average rainfalls in various localities.

The actual maximum and minimum amount of rain which falls in any one year, is compared with the calculated amount.

The calculated maximum rainfall is obtained by the means already alluded to, namely, by adding one-third to the average annual rainfall, and the calculated minimum rainfall is obtained by deducting one-third from the average.

The calculated average annual rainfall for three consecutive dry years, is also compared with the actual rainfall in that period.

The calculated amount is obtained by deducting one-sixth from the average annual rainfall.

These figures have not been selected for the purpose of exemplifying the principles contained in this paper, but all the records of rainfall which could be obtained in a very short period were made use of, and the result proves that the mode of calculation adopted is in most cases practically correct.

Table No. 2 contains the principal dimensions of some reservoirs, and shows how extremely different are the storage capacities in proportion to the area of the watershed, and also the great variety of dimensions adopted in the construction of the embankments and puddle wall.

NATURAL LAKES USED AS RESERVOIRS.

Another branch of the subject is the adaptation of natural lakes to the purpose of water supply.

In this case it is necessary to obtain power, to raise and lower the natural water level of the lake to such an extent, as will give sufficient storage accommodation between these two levels, to contain the requisite supply of water for the period of longest drought.

In fact, all the calculations respecting rainfall, evaporation, and absorption, compensation water, &c., &c., already given, apply equally to lake reservoirs, and entirely artificial ones, for the former may be called reservoirs constructed on the top of the lake water, instead of on the ground.

SITE OF RESERVOIR.

Having made all the necessary calculations relative to the amount of water which can be impounded on any particular

watershed, it becomes necessary to determine upon the site of the reservoir.

Here the configuration of the ground forms a very important feature.

The most advantageous site is one, where a comparatively small embankment thrown across a valley, will form a reservoir of great capacity, of which only one side will be artificial, the water being retained on the remaining sides by the rising ground.

Such favourable circumstances are not often met with, particularly where the reservoir is required to be of considerable size.

Very frequently other embankments have to be constructed, in addition to the main one, in order to prevent the water from escaping through smaller valleys which lead out of the principal one.

In other cases, two embankments are required to close up diverging valleys, and in some instances, in order to obtain the required water space, banks have to be built on two or more sides of the reservoir, and even on the top of the highest land of the site.

But no general principles can be laid down on this subject, and the engineer must be guided by his own judgment in selecting the site for his reservoir.

NEW COURSE FOR STREAM.

Before commencing to raise the bank, it is frequently deemed desirable to cut a new course for the stream or river which it is proposed to impound, especially when the river is of considerable size and liable to heavy floods.

By commencing at the point where the top water level of the reservoir intersects the stream, and cutting a new channel of sufficient magnitude following a contour line on the hill side, until the site of the embankment is passed, the river can be conveyed away into its natural course without causing any inconvenience or injury to the new works.

In very large undertakings it is advisable to make the diversion of the watercourse of a permanent character, and by this means, provide the opportunity of passing heavy floods into the original stream without entering the reservoir, should they occur when it is already full, or when the water is too turbid to be utilized with advantage.

This diverted stream course is also extremely useful in regulating the speed at which the reservoir is filled when completed, and this is a very important point, which is too often overlooked.

SITE OF EMBANKMENT.

Too much attention cannot be given to the examination of the actual site of the embankment itself, and every possible information should be obtained on this head before commencing operations, as it has happened that owing to this precaution being neglected, the engineer's estimate of the cost of the works has been exceeded to a very considerable extent, and in some instances works have been abandoned owing to the treacherous nature of the ground on which they were commenced after large sums of money have been spent in endeavouring to obtain a reliable foundation.

Trial shafts, or borings, but preferably the former, should be sunk on the site of the embankment, both on the centre

line and on each side of it, clear of the foot of the slopes, so that the nature of the ground may be accurately ascertained.

Of course, the more watertight and solid the ground is found to be, the better it is; but the surface appearance, more especially in mountain districts, is so very deceptive, that no one ought to dispense with these practical trials, or be content with inferences drawn from surface observations, or from the results of only one or two trial holes.

In the first instance, it should be ascertained whether there is any bog, or other soft compressible material, which is unable to bear the weight of the intended bank, and which will require to be removed.

Next and most important, an unbroken strata of watertight material must be found and proved to extend from one side of the valley to the other, and to rise above top water level on both sides.

It is very false economy to suspend the trials when a watertight material is reached ; they should be continued into this material, to prove that it is continuous, and of a sufficient thickness, as frequently layers of gravel or other pervious materials have been found *under* beds of clay which have been assumed to be a satisfactory foundation. These trials are indispensable when a reliable estimate has to be made of the probable cost of a reservoir, constructed on the plan usually adopted in this country, viz., that of making an embankment with a puddle wall in the centre, which puddle wall is carried down below the surface of the ground until an impervious material is met with.

INDIAN RESERVOIRS.

In India and elsewhere very extensive reservoirs or bunds have been constructed without using a puddle wall or sinking a puddle trench.

Some of these bunds are larger than any reservoirs in England.

Two reservoirs in Ceylon, described by Sir James Emerson Tennent, are of the following dimensions.

One has an embankment 12 miles long, and the area submerged measures 40 miles round.

Another has an embankment over a mile in length, and the circumference of the lake is 20 miles.

The Cummum Tank, in the Madras Presidency, is stated by Mr. C. Brumell to be five miles long, and to have a maximum width of three miles, enclosing a water space of eight square miles.

The bund or embankment is 102 feet high.

The slopes and dimensions of the embankment and bye-wash of this reservoir, are well worthy of being studied by English engineers; and it is astonishing to find how far advanced in the science of reservoir making, were the Hindoos in the earliest period of their history.

A very interesting description of this tank, together with some drawings, are to be found in the report on the Sheffield water works failure, 1864.

Some engineers have advocated the adoption of the Hindoo plan of constructing banks without puddle, but depositing the materials of which the embankment is composed in very thin layers, each layer being well consolidated by being trampled under foot by the numerous labourers

(men, women, and children) employed on the works, who would carry the earth to its destination in baskets on the top of their heads.

Others recommend that a thick bed of concrete should be placed all over the site of the embankment ; which should be built in the usual way with a puddle wall in the centre.

I am not acquainted with the geological formation of the site of the Indian bunds, or whether the whole of the interior of the reservoir is puddled over, but unless the ground on which the bank is raised is watertight in itself, or the puddle placed on the bottom of the reservoir, it is difficult to understand how they can be perfectly watertight.

Moreover, have any observations been made, as to the amount of rainfall, the proportion impounded, the loss of water from the reservoir during dry weather, &c., which will prove whether these reservoirs are perfectly watertight or not ; for a bed of porous material lying at some depth below the surface, may communicate with the body of impounded water, and convey a proportion of it away underground for a considerable distance to a point where it may reappear in the form of a spring, and against this defect the plan of concreting the site of the embankment would not form any remedy.

The probability is, that the Hindoos did not use puddle trench, because the idea never occurred to them ; and if it did, they had not the mechanical appliances at their disposal to enable them to carry it out.

Until some more economical and expeditious mode of rendering a reservoir watertight is discovered, the practice

of sinking a trench down to the rock or other watertight material, and filling it with puddle, will in all probability continue to be the acknowledged practice in this country.

These remarks do not apply to small reservoirs, which, in most instances can be more economically constructed by covering the bottom with puddle, and carrying it under the embankment to the puddle wall to which it is connected.

SINKING PUDDLE TRENCH.

In sinking a puddle trench the first point to be determined, is the necessary thickness of the puddle wall at the surface of the ground, and on this point very wide difference of opinion exists.

In almost every instance this thickness is made to depend upon the height of the embankment above the surface.

A great variety of dimensions have been adopted by various engineers for the thickness of the puddle wall at the top of the embankment, which vary from three feet to ten feet.

Usually the puddle wall is designed to batter on each side, so as to increase in thickness at the surface in proportion to the height.

Every possible ratio of batter may be found in the various reservoirs in this country, and in some instances the puddle wall is of uniform thickness throughout.

A batter of 1 in 8, or 1 in 12 on both sides of the wall is the rate most commonly adopted.

Mr. Robert Rawlinson considers that the puddle wall should be one foot thick at the surface of the ground, for every three feet in height of the embankment. Thus a

bank 100 feet high would require a puddle wall $33\frac{1}{3}$ feet thick at its base.

To obtain this result the wall would have to be about 4 feet thick at the top, and have a batter on each side of $1\frac{3}{4}$ inches per foot.

But a great deal depends upon the nature of the material used for the embankment, and of the strata in which the puddle trench is sunk; for though puddle properly formed of strong clay thoroughly well tempered is perfectly reliable as a material which is impervious to water, yet it is unable by itself to bear any considerable pressure, but cracks and gives way, unless it is uniformly and well supported by some strong substance.

Having determined upon the thickness of the puddle at the surface of the ground, and having carefully marked out the same, the trench may be commenced.

Many engineers design the trench to *diminish* in width in the same proportion to its depth below the surface, as the puddle wall diminishes when it rises above the ground.

The reason for this is not very apparent, as in most instances the ground through which a puddle trench is sunk is so porous, that when the reservoir is full, it becomes completely saturated with water, which may be considered as the increased depth of the reservoir itself, and consequently the hydraulic pressure on the puddle increases in proportion to the depth of the trench; and therefore the puddle should continue to increase in thickness below ground in the same ratio as it is designed to do above the surface.

This would be an expensive operation, as in most cases the exact depth to which the puddle trench will require to

be sunk, is rarely accurately known, however carefully the preliminary trials have been conducted, and the excavation would require to be executed far wider than absolutely necessary in order to allow for the increased thickness of the puddle owing to the extra depth, should the foundation prove to be unfavourable.

It would be almost impossible to excavate the trench to the exact intended form of the puddle, as in most cases, the ground would not stand, if undermined in this manner, however strong the timbering might be which was employed.

The other method, already alluded to—viz., of diminishing the width of the trench, in proportion to its depth, is also open to serious objections.

In the first place, it is extremely difficult and expensive to dress the sides of a deep trench to a steep batter, and the workmen rarely attend to it properly.

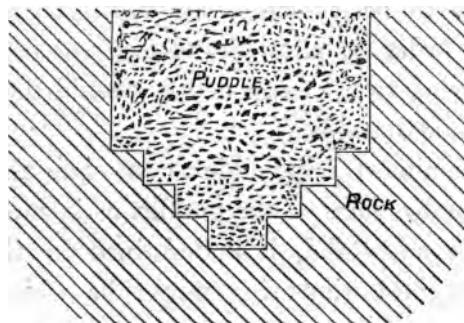
It is also difficult to timber it substantially.

Moreover, if the depth of the trench is considerable, and the width at the surface not great, it becomes so narrow as to be difficult to work in, and the thickness of the puddle insufficient to retain the water.

Taking all these circumstances into consideration, the plan of sinking the trench with perpendicular sides, and thus retaining the puddle at the bottom of the trench, of the same thickness as it is at the surface, is perhaps the best which can be adopted.

When solid rock is found at the bottom of the trench, it is frequently cut into small steps or grooves, which run parallel with the centre line of the embankment, and tend

to prevent the water from creeping between the rock and the puddle, thus—



Formerly it was universally the practice to make the bottom of the trench exactly level, ascending with perpendicular steps as the rock or other watertight material got nearer the surface.

In modern practice a different mode has been pursued, namely, that of making the bottom of the trench incline with tolerable uniformity from each side to the deepest point.

By this means, as the puddle consolidates it settles towards that spot, by sliding on its bed upon which it always rests ; whereas, where steps of any considerable height are used, the puddle, which naturally settles most where the trench is deepest, has a tendency to break away from that portion which is supported by the step above it, and also to fall away from the vertical side of the step, and thus afford a means of escape for the water.

If steps are used at all on the longitudinal section of the trench, they should be rather level stages with steep inclines between them.

The annexed drawings, Nos. 1, 2, 3, 4, 5, and 6, show several important trenches now in course of construction.

Great care must be taken to prevent the puddle from being injured by the wash of water from springs which are so frequently met with in sinking.

In rock containing fissures from which water issues, they should be carefully plugged with wooden or iron plugs, where of moderate size, or caulked with oakum when small.

If the water rises through beds in the rock from under the trench, it must be sunk below them and until no water rises in the bottom.

In very wet rock trenches, Portland cement concrete is generally employed, instead of puddle, to fill up the bottom portion, and in some instances the puddle is placed between two walls of concrete or brickwork which protect it from being injured by the wash of the water.

FILLING PUDDLE TRENCH.

Having obtained a satisfactory bottom to the trench, and having got below all springs and carefully caulked up all fissures, the filling up of the trench may be commenced.

If concrete is used for this purpose it should be of the best quality and carefully mixed, due care being taken to test the strength of the cement used.

The puddle should be composed of the stoutest and toughest clay which can be procured; all soft, miry, and puffy clays being rejected, and should be placed without admixture of stone, sand, or soil, or other adventitious matter in regular and level courses in its own trench or place, and so that no single layer after being worked shall exceed nine

inches in thickness. In deep trenches in which much timber has been used, it is impossible to work the puddle in its place in the trench, owing to want of room for the men. It must, therefore, be well worked and tempered on the surface, and tipped into its place. Care should be taken to tip it in such a manner that it may not require much levelling in the trench.

In very wet trenches gravel puddle may be used with advantage.

Gravel puddle should be made of the same description of clay, as the clay puddles. The clay ought, before being placed in its situation, to be thoroughly and uniformly mixed with not less than half its own bulk of round gravel or broken stone, nor more than as much as its own bulk, nor should any gravel or stone be mixed therein which shall not have passed through a screen of $1\frac{1}{2}$ inch mesh, nor which should be capable of passing through a screen of less than $\frac{1}{2}$ inch mesh.

Having filled up the trench to the surface and carefully drawn all the timber, which is frequently a difficult and dangerous proceeding, the construction of the puddle wall and embankment may be proceeded with.

PUDDLE WALL AND EMBANKMENT.

The materials for the embankment should be carefully selected, and care taken not to excavate anything from the interior of the reservoir for the purpose of making the embankment, the removal of which may facilitate the access of water to the puddle trench, or even to fissures in the rock which might afford the means of escape to the water intended to be contained in the reservoir.

In fact, if possible, nothing should be removed from the interior of the reservoir below the water line, but this condition can rarely be enforced, owing to the difficulty of obtaining materials from any other site.

The slopes of the embankment are subjects on which some difference of opinion exists, but there can be no doubt that the flatter the water slope is made, the better it is for the stability and durability of the work, and the water slopes of most reservoir embankments are now being made much flatter than was formerly the case. The rate of slope has gradually decreased from $1\frac{1}{2}$ to 1, to 2 to 1, $2\frac{1}{2}$ to 1, and 3 to 1, which latter is now adopted in most cases (see table No. 2, appendix.) The importance of a flat water slope can scarcely be over estimated, as by its use the force of the waves is materially reduced by the gradual shoaling of the water, thereby diminishing the wear and tear on the pitching and shingling of the bank ; but also the pressure of the water having a downward tendency, and pressing on the flat inner slope, helps as it were to retain the bank in a perpendicular position, instead of trying to push it over, as it would do a perpendicular wall.

Moreover the flat slope becomes more consolidated in construction and has less tendency to settle, and thereby injure the puddle wall, when it becomes saturated with water than a steeper slope would have.

All clay (which is not required for the puddle) and other homogeneous material which can be procured, should be deposited in the water slope, leaving the stones, gravel, and other porous substances to be deposited in the back bank, or on the down stream side of the puddle wall, always reserving a certain thickness of strong, sound material to place

immediately against the back of the puddle, in order to support it as much as possible.

It is usually specified that a wall of carefully selected materials should be placed on either side of the puddle wall, and the thickness of each of these walls is generally equal to that of the puddle itself.

The slope of the outer bank is usually 2 to 1, though $1\frac{1}{2}$ and $2\frac{1}{2}$ to 1 are sometimes adopted.

In very lofty embankments it is usual to make a level break or berm at about half the height, varying from 10 to 20 feet in width so as to increase the thickness of the bank at its base to a greater extent than the slope alone would give.

The width of the embankment at the top, varies considerably in different instances ; ten feet appears to be the minimum top width for banks of any magnitude and one-third of the height of the bank is the greatest width which appears to have been suggested for this purpose (see table No. 2, in appendix.)

It is essential that all soft or boggy material should be cleared away from the site of the embankment, and if on shelving ground, it should be carefully benched and levelled.

Drains should be constructed on the down stream side of the puddle trench, in order to convey away any water which may arise on the site of the bank from springs or surface drainage.

The embankment should be slowly raised in thin layers, not exceeding one foot in thickness, and one layer should be completed over the entire surface of the bank before another is commenced.

To ensure this being done constant attention is required from the superintending engineer, as it entails a great deal more trouble and expense to the contractor than constructing the bank with high tips.

No rails should be permitted to be used on the bank, but the whole of the material should be deposited by dobbin or hand carts and barrows, the route traversed by them being changed as often as possible, in order that their passage may thoroughly consolidate and incorporate every portion of the bank.

If railways are permitted to be used on large banks, unequal settlement is sure to take place, unless the material used is of an exceedingly binding nature, such as some shales and gravel mixed with clay which set almost like concrete.

Many clays and marls which appear to be sound and good when excavated, are totally unfit for the formation of reservoir embankment, as when they are saturated with water, they run out like cream; and one case of a railway embankment constructed under the superintendence of the author, with clay from the lias formation, the slopes of which were designed at $1\frac{1}{2}$ to 1, settled down during the wet season, in some instances to as much as 5 to 1, and in fact completely filled up the valley in which the railway was situated, and could not have been completed, if an embankment or dam of dry sand had not been constructed at the end of the valley, in order to stem the on flowing tide of semi-liquid clay.

PITCHING AND SHINGLING.

The water slope of a reservoir embankment is usually protected from the action of the waves by a thick layer of

shingling or broken stones, placed roughly on it to within ten or twenty feet of top water level, from which point it is covered with pitching, or large stones placed edgeways on the bank upon a layer of broken stone, and which presents the appearance of a dry rubble wall laid upon the slope.

In a few instances, squared blocks of stone have been adopted for this purpose, but is too expensive for general use.

Some engineers recommend that the water slope should be covered with a layer of puddle below the pitching and shingling, but the utility of this plan is not very apparent, as the inevitable settlement of the bank consequent upon the reservoir being filled, is almost certain to fracture the puddle lining, and in any case it is impossible to render this lining so perfect as to exclude the water entirely from the bank, as even if it could not penetrate the puddle lining, it would pass under it, and thus gain access to the bank until stopped by the central puddle wall, unless the bottom of the reservoir happened to be perfectly impervious to water—a circumstance, which, unfortunately for constructors of reservoirs is of almost unprecedented occurrence.

HEIGHT OF BANK.

The height of top bank above top water level varies from three feet to nine feet, and should depend to some extent upon the area and position of the reservoir, and the liability of lofty waves being thrown against the bank, owing to its being constructed across the direction of prevailing heavy gales.

In such cases it is advisable to build a breastwork or wall

about 3 or 4 feet high above top bank level, which need not be of very great thickness, as it has only to intercept the spray and prevent it from washing into, and injuring the down stream slope.

This latter is usually soiled and sown with hay seeds, and a road or footwalk is generally made on the top of the embankment.

Numerous instances exist in which public roads, which formerly traversed the bed of the valley, have been raised and carried on the top of the embankments of reservoirs, with manifest advantages to the public using the road.

OUTLET.

With regard to the best mode of providing an outlet for the water from the reservoir, a complete revolution has been made since the failure of the "Dale Dyke" reservoir at Sheffield in 1864.

Prior to that period the plan generally adopted consisted in the construction of a culvert under the embankment, which contained a pipe or pipes passing through a watertight stopping built in the culvert, and furnished with valves which were raised or lowered as required.

In numerous instances a tower was built from the end of the culvert and near the foot of the water slope, extending to above top water level and provided with several valves at various stages, so as to enable the water to be drawn off at different heights.

These valves are usually only short pipes extending through the walls of the tower, and furnished with sluices which can be lifted from the top of the tower by means of chains or screw spindles, and thus allow the water from the

reservoir to pass through them all to the bottom of the tower, and flow away through the culvert under the embankment, which, by this means was open from end to end, and did not require any stopping.

If the water had to pass into pipes, they were fixed into the down stream side of the culvert. These water towers are reached from the embankment by means of footbridges which span the water slopes.

Frequently the water tower also serves as an overflow from the reservoir by being constructed with the coping to correspond with top water level.

When the reservoir is full the water flows over the coping of the tower, and passes away through the culvert.

By the adoption of this plan in large works, the circumference of the tower, and the diameter of the culvert have to be made of great size, and an outlet must be provided from the culvert into the nearest stream course.

There is also another objection to this plan, namely, that the flood water has to be passed into the pipes whatever its condition may be, whereas in many instances the water which flows into a reservoir in time of flood, is not fit to be used for the supply of a town, and is therefore sent to waste by means of the stream course already referred to, or if permitted to flow into the reservoir, the water used at such periods is drawn from a low and comparatively undisturbed level.

At the Manchester water works some very ingenious appliances have been introduced, by means of which the flood waters which are very turbid and discoloured, are passed by means of watercourses, which intercept the stream, into reservoirs devoted exclusively to storing water for compensa-

tion purposes, for which colour and purity are not so essential as for the supply of the town, the latter being drawn from other reservoirs which receive the clear water only.

Other reservoirs are provided with outlets by means of a culvert containing pipes, but with a shaft for the valve spindles immediately in front of the puddle wall, which is built through the embankment to top bank level.

In some instances, pipes unprotected by culverts have been laid through the embankment, and, happily in very few cases these pipes have been closed by valves placed at the foot of the dry slope of the bank.

Nothing worse than this plan can probably be devised, for the pipes are always full of water, are not accessible for repairs, cannot even be examined unless they are of unusually large diameter, so as to enable a man to crawl inside them, and if any defect should occur, the leakage caused thereby would have a most detrimental effect on the stability of the work above them, and might end in undermining the bank itself.

The culvert plan is also open to objection, however carefully it may be executed.

Where the pipe or culvert crosses the puddle trench, especially if the latter be deep, settlement may be expected to occur.

The culvert is usually placed over or near the site of the old stream course in order to tap the reservoir at the lowest level, and, consequently the height of the bank is generally greatest at this point.

The puddle trench being filled in with a soft, yielding material, which naturally settles in time with the weight of

the culvert and bank upon it, the culvert or pipe is liable to fracture.

In some instances arches have been constructed over the trench springing from the solid ground on either side, and forming a support to the culvert, but these arches which answer their purpose in one respect, namely, that of supporting the culvert, only serve to increase the weakness of the puddle by piercing it, and thus affording to the water the means of creeping along it through the puddle as it will do along the culvert or pipe, unless they are furnished with water collars or flanges which will turn the creep of the water, and are also well encased in a layer of puddle or concrete.

In order to obviate all these difficulties, the outlets from some reservoirs are furnished by means of tunnels driven through the solid ground, round one end of the embankment and under the end of the puddle wall, or under the bank itself.

The former plan is being adopted at the new Yarrow reservoir, now in course of construction at Rivington for the Liverpool corporation, and at the Llanefydd reservoir which is being made for the Rhyl District Water Company, and also at the Wayoh reservoir belonging to the Bolton corporation.

In the former instance the tunnel is 217 yards long and 8 feet diameter, and is driven through hard shale and lined with masonry.

At Llanefydd the tunnel is 70 yards long, and of oval shape, 5 feet by 4 feet, and is cut through the solid rock.

In both instances there is a valve shaft situated in line

with the puddle trench, and extending from the tunnel to the surface of the ground at top bank level.

In the Yarrow reservoir this shaft is lined with masonry, and the puddle wall is carried all round it and tied into the hill side.

At Llanefydd the puddle will not extend to the shaft, the rock in which it is sunk being watertight.

At the bottom of the shaft the tunnel is completely filled up with a plug composed of brickwork set in cement, and faced with Staffordshire blue bricks.

The chamber at the junction of the tunnel and shaft is larger than the remainder of the tunnel, so that the plugging may be thoroughly well keyed into the sides and rendered immovable.

In the plug the outlet pipes and valves are inserted.

They should always be in duplicate, so as to provide against accidents.

There should be two outlet pipes, each provided with two valves, one of which should consist of a pipe extending from the outlet pipe to the top of the shaft and provided with grooves, capable of receiving an ordinary sluice or paddle, which could thus be lowered into the outlet pipe in front of the other valve, which could be of the ordinary spindle pattern, and thus in the event of any accident happening to the latter, which would be constantly in use, the paddle could be lowered, and the valve taken out and repaired, the supply being continued in the meantime through the other pipe.

The portion of the tunnel between the valves and the reservoir should be lined with brickwork or masonry, the thickness depending upon the nature of the ground, for,

however hard the rock through which the tunnel is driven may be, still the combined action of the water and weather has a tendency to dislodge portions from the roof, which may be washed into the valves, and thus cause a serious injury.

At the Wayoh reservoir the tunnel mouth in the reservoir is closed by a brick wall, and valves are placed immediately behind the wall.

The tunnel is thus rendered dry throughout the whole length.

The valves for ordinary use are placed in a shaft in the centre of the tunnel, those near the mouth being intended for use in cases of emergency only.

The mouth of the tunnel when open should be protected with a strong iron grating, and it must be constantly borne in mind that, after the valves are once closed, and the water allowed to rise in the reservoir, this portion of the works cannot be examined without letting off the water, and if the valves get out of order, this cannot be effected without considerable expense.

It has been proposed, in order to diminish the cost of the tunnel, to construct it considerably above the bottom of the reservoir which would lessen the length.

By this means the water could be drawn off through the tunnel under ordinary circumstances, but in times of extreme drought, when the reservoir is very low, or when it is desired to empty it altogether for repairs or cleansing purposes, it is proposed to draw off the residue of water which remains below the tunnel by means of a siphon pipe constructed for that purpose, and reaching from the deepest portion of the reservoir up to the tunnel through which it passes, and con-

veys the water into a tank on the down stream side of the bank. One objection to this plan is, that during the construction of the embankment, the syphon alone would be available for keeping the reservoir empty, and would therefore have to be made large enough to convey the greatest quantity of water which could come into the reservoir during a flood; whereas if the tunnel is kept at the lowest point of the reservoir and the plugging, pipes, and valves left out until it is desired to impound the water, the floods can pass away through the entire area of the tunnel, which is usually more than sufficient for this purpose.

OVERFLOW.

Of equal importance with the outlet for the water which the reservoir is constructed to supply, is the overflow or means of escape for those floods which the reservoir cannot contain, or which perhaps pour into it when it is already full, and it is this last contingency which should be provided for in designing the overflow or byewash, as it is commonly called.

The length of the waste weir should depend on the area of the watershed which drains into the reservoir, and the greatest amount of rain which has been ascertained to fall in that district in any one day.

Having these particulars, it is easy to calculate the quantity of water which will flow over a weir of given length, and allowing a maximum depth of—say six inches over the weir.

The length of the weir must be increased until the quantity of water which will flow over it in a given time, is

equal to the largest amount of water which can pass into the reservoir in that period.

An ordinary rule adopted in England is to make the waste weir, three feet long for every 100 acres of watershed ; but this, as well as the practice of making the width of the byewash to equal one foot for every acre of water surface of the reservoir are merely rules of thumb, and should not be relied upon.

The byewash proper, or channel for conveying the water away after it has fallen over the waste weir, is not made so wide as the weir itself, but can be considerably reduced, as the water may be made to flow through it with increased depth, and the greater the rapidity with which it falls, the narrower it may be made within certain limits.

In order to relieve the reservoir in times of flood, and to prevent the water from rising too high, a portion or sometimes the whole length of the masonry of the waste weir is finished two or three feet below the intended top water level, and the height is made up with planks, which can be removed at pleasure, so as to ensure the safe passage of floods, or to lower the water level for any purpose.

It has been suggested that the byewash should only be constructed in the first instance to about three-fourths of the height of the intended embankment, and should gradually be raised to the full height after the reservoir had been completed for some time, the embankment become consolidated, and the works proved to be able to stand the pressure brought upon them.

In most instances this would prove a very expensive plan, and would involve the cutting away of a considerable por-

tion of the solid ground, which it is not desirable to disturb; for, in almost every reservoir, the byewash is made round the end of the bank, and cut into the hill side and not brought over the embankment itself.

Either the adoption of the diverted stream course already alluded to, or of an outlet of sufficient capacity to command the level of the water in the reservoir, but especially the former, are preferable for many reasons.

By these means the rate at which the reservoir is filled is regulated, whereas in the other case it may fill very rapidly up to the temporary level of the byewash.

The floods can also be kept entirely out of the reservoir if desired.

Of the mode of constructing the byewash, the form most generally adopted for the waste weir is a segmental or semi-circular coping placed at top water level, of sufficient length to enable the floods to pass rapidly over it, and having a vertical fall for the water on the down stream side of one or two feet.

As already mentioned, in most instances an opening is left in the coping, which is filled up with planks, which can be removed at pleasure, so as to facilitate the escape of the water.

In other cases, the coping of the waste weir, is built a couple of feet below top water level for its entire length, and on it are placed stone or iron pillars, with grooves on their sides, to receive the stop planks, all or any of which can be removed when required.

After falling over the waste weir, the surplus water has, in most instances to be conveyed into the old stream course,

which is frequently a considerable distance below top water level.

In order to convey the water gradually from one point to the other, and to prevent it acquiring too great a velocity, the byewash is usually carried for some distance down the valley, and in some cases follows very nearly the line of intersection between the foot of the dry slope of the embankment and the surface of the ground.

Some engineers adopt for the floor of the byewash inclines occasionally broken by steps; others confine themselves to steps broken by level or nearly level landings.

Where the nature of the ground will permit the landings to be constructed at frequent intervals without incurring much additional expense, the latter is perhaps the best plan, as by this means the byewash is made much shorter than by using inclines, which must be made with a flat gradient to prevent the velocity of the water injuring the masonry.

Where steps are used the fall from one to the other should be made very small, not more than 9 inches or at the most 12 inches.

The tread of each step should equal at least twice the fall, the wider the better: the great object to be attained, is to prevent the water from leaping *over* one or more steps, and thus falling with greatly increased force.

The steps should not have a continuous fall of more than 5 feet, but should then be broken by level landings of at least 5 feet long.

Where the stone can be procured, it is advisable to make each step in one piece as regards the tread and height, many lengths of stone being required in large works to reach across the whole width of the byewash.

It is also advisable to make the steps curved on plan, forming segmental arches springing from the side walls.

Many byewashes have been constructed on entirely different principles to those just mentioned, and have falls from step to step of two and three feet, the width of the steps being only equal to, or less than the fall; and in one instance, a byewash 50 feet wide, constructed in this manner was nearly destroyed by the immense force which the water acquired in falling over these high steps; other works constructed with small steps, as suggested, have given a great deal of trouble, owing to the rise of the step being constructed of stones set on edge, and the remaining width of the tread of the step being filled up with small pitching, through which the water percolated, and in time undermined the foundation of the front stones of each step, and thus caused constant repairs to be required.

A layer of puddle or concrete under the bottom of the byewash is very generally adopted, and is especially necessary between the waste weir and the central puddle wall in the embankment, in order to prevent the water from creeping under the pitching and injuring the puddle.

If the ground is sound, the bed of concrete or puddle may be dispensed with after the embankment has been passed.

CLEARING INTERIOR OF RESERVOIR.

The removal of the brushwood, vegetable matter, and boggy or peaty material from the interior of the reservoir should be carefully attended to, when the water is intended for the supply of a town, as any material of this description which may be left tends to discolour the water and involves

increased expense in filtration; and moreover most engineers, who have been engaged on works of this description, know how soon a prejudice is created against the water supply, if the slightest discolouration can be noticed in it, though the water itself may be far purer and more wholesome than the bright, sparkling well water which the inhabitants of the district have hitherto enjoyed, and which, though perhaps more palatable than the flat, vapid rain water collected in the hill districts, often contains elements most injurious to health.

FILLING A RESERVOIR.

The reservoir being now completed, nothing remains to be done, but to fill it, or rather allow it to fill itself by closing the valves, and it frequently happens that this operation is not conducted with sufficient care.

Too often the reservoir is urgently required, and there is great inducement to fill it as rapidly as possible, and no method could possibly be employed more likely to endanger the watertightness and stability of the work.

It is essential that the water should rise as slowly as possible, in order that the water slope may settle very gradually; for, as soon as the water is admitted by permeating the slope, it causes it to subside and to slip away from the puddle wall, and if this takes place suddenly, the puddle, being unsupported, is apt to crack, and becomes distorted through the weight of the back bank pressing against it, which it cannot sustain.

It is at this period that the absolute necessity of constructing the bank in very thin layers becomes so apparent,

as the better consolidated the bank is, the less settlement takes place on the admission of water.

If the contour course for the stream is adopted, it now becomes of the greatest service, as by this means, or the adoption of very large outlet pipes, the rate at which the reservoir is filled can be regulated at pleasure.

Having thus traced, though very imperfectly, the numerous subjects which have to be considered by the engineer in designing and constructing a catch water reservoir, this treatise must be brought to a conclusion without attempting to enter into a description of the numerous details connected with the distribution of the water, such as filter beds, clear water tanks, service reservoirs, pipe lines or conduits, guages for measuring the amount of water supplied to millowners and others, valves of various descriptions and numerous other items which do not properly come within the limits described by the title of this work.

DESCRIPTION OF PLATES.

PLATES I AND II.

THESE plates represent the longitudinal and cross sections of one of the two embankments now in course of construction, in order to form the New Yarrow Reservoir at the Rivington Waterworks, belonging to the corporation of Liverpool. This reservoir will form a very important addition to these already extensive works. It will not introduce any fresh source of supply, but is intended merely to increase the storage capacity of the works. The Yarrow reservoir will consist of a water space of 73 acres, having a maximum depth of 90 feet, and will contain about 1000 million gallons. Two embankments are required, owing to the valley dividing into two branches, and they will contain upwards of one million cube yards of earth.

The Yarrow embankment, which is the one illustrated in plates 1 and 2, is the shorter of the two; it will be 181 yards long at the top, and have a maximum height of 90 feet.

The plates shew the nature of the material met with in sinking this trench, and also how essential it is to sink trial shafts, and not to be content with boreholes, if the exact nature of the foundation has to be ascertained.

After the several porous deposits had been removed, extremely hard grit rock was found, which would have been considered a sound foundation, if it had been reached by a bore hole, but it proved to be full of large fissures, all of which made considerable quantities of water; this had to be excavated until solid dry rock was reached, and the expense of doing so was considerable.

In order to overcome the large quantity of water which flowed into the trench from both sides, a pump shaft was sunk at the back of the trench near section No. 9 as shewn upon the plates.

A 9 inch pump was placed in this shaft which kept the down stream side of the trench dry.

After obtaining a good foundation throughout, in order to get command of the water on the up-stream side, which chiefly came from an open seam along the side and near the bottom of the trench, a drain was formed along the seam leading into a vertical 9 inch duckfoot pipe, near section No. 10, from which a 9 inch pipe with a collar was laid across the trench into the bottom of the pump shaft.

These pipes were buried in, and the bottom of the trench covered with Portland cement concrete, composed of one measure of cement to 3 measures of gravel and sand, to about one foot above the level of the open seam and side drain.

By this means a perfectly dry trench was obtained in which the worked puddle was placed, the vertical pipe being carried up by adding pipes 2 feet long as the puddle advanced, all the water being carried off through the pipes into the well, until the work had advanced sufficiently to enable the water to be removed by means of another pump placed between cross sections No. 11 and 12.

A dead end was then placed on the pipe in the well, and the pipes filled with cement concrete.

The well was filled with brickwork set in cement and with concrete up to the top of the rock, after which the pump was removed, and the remainder of the shaft filled with puddle.

This plan of sinking a shaft at the back of the puddle trench ought to be invariably adopted in all extensive works; as by this means the pumps are kept clear of the trench, and are more easily maintained in good order.

The great difficulty is to select the proper position for the pump shaft, so that it shall be in the deepest part of the trench, and the same remark applies to fixing the pumps in the trench itself.

The outlet from this reservoir is by means of a tunnel and valve shaft shewn upon plate 1, and described on page 34.

PLATES III AND IV.

These plates represent a portion of the longitudinal and cross sections of the second and larger embankment of the Yarrow reservoir.

In this case the bottom of the trench is very irregular, a ridge of watertight shale dividing the valley into two deep ravines filled with clay, gravel, and stones.

The deposit of clay, which was used for puddle, and met with in one portion of the trench, is extremely curious and deserving of attention.

A great difference also existed between the quantity of water made by the two holes, the one in the centre of the valley making much more than the other.

In the former instance the trench was excavated into the shale for a depth of about 6 feet, when a great quantity of water flowed off the top of the shale into the trench on both sides; in order to preserve the puddle from the wash of water and to ensure a sound foundation, brick walls in cement, 14 inches thick, were built on each side along the deep portions of the trench, having vertical grooves left at the back, in order to give free passage for the water down to the 6 inch pipes A and A' which lead into small wells at the feet of the pump stocks B and B' 9 inches in diameter.

These stocks were kept connected with the pumps, until the trench was re-filled to a height of 27 feet above the deepest part of the trench, when they were disconnected, and those portions which were left in were filled in solid with Portland cement concrete.

The space between the brickwalls was also filled in to about 3 feet below the top of the walls with concrete, composed of two measures of gravel and one of sand, to one of Portland cement: this gave a dry foundation for the puddle.

The other deep portion of this trench gave very little trouble, the puddle being placed direct on the shale without the intervention of concrete or brick walls.

PLATES V AND VI.

These plates being respectively the longitudinal and cross sections of the puddle trench and embankment of the Llannefydd reservoir, now in course of construction under the superintendence of the author for the Rhyl District Water Works Company, afford a very striking illustration of the difficulties which are frequently met with in obtaining a sound watertight foundation for the puddle ; and also of the danger of commencing the puddle wall on the first watertight material which is met with, without ascertaining that there is no pervious strata lying under it, which may communicate with the interior of the proposed reservoir.

In this instance the puddle was intended to be placed on the stony blue clay, which was found at an average depth of 13 feet from the surface.

A bed of exceedingly porous and shattered shale was found at the east end of the trench lying between the rock and the impervious clay. It was attempted to remove this shale by means of a heading driven under the clay, and at the same time a trial shaft was sunk at the west end of the trench, which passed through the clay and entered into a bed of gravel which made a large quantity of water. By means of bore-holes this bed of gravel was discovered to extend right across the valley, and by pumping alternately at opposite ends of the trench, it was proved that this bed of gravel formed a perfect water communication under the clay. It therefore became absolutely necessary to carry the puddle down to the rock for nearly the whole length of the embankment.

The excavation of the trench was accordingly commenced, the two ends had reached the rock, and the central portion had passed through the clay, and was being excavated in the gravel at the depth marked as the present bottom of the trench when, either owing to defective timbering or else on account of the timber not being fixed as rapidly as the trench was excavated, and thus allowing the gravel to run and the sides of the trench to settle, the timber

suddenly gave way and about 100 yards of the middle portion of the trench collapsed, the two sides coming close together.

The cracks in the ground caused by this collapse extended to more than 80 yards from the centre of the trench.

The work had up to this time been executed by contract, but since this accident it has been carried on under the direction of the author without the intervention of a contractor.

Owing to the disturbed state of the ground, and the difficulty of working through the old timbers, the trench has not been re-opened from the surface, but a wide open cutting made as shewn in the cross section on Plate 6, the slopes having a batter of $\frac{3}{4}$ to 1, which is as steep as can be made in the material. This cutting has now nearly reached the depth to which it is intended to excavate it, after which the old trench will be re-opened, repaired, and carried down to the rock.

In order to economize the cost of timber as much as possible, the eastern half of the damaged trench will be first sunk to the rock, and filled with puddle, the end of the puddle adjoining the western half of the trench being stepped back as the work proceeds; by this means the timber as it is drawn from one-half of the trench will be used for repairing the other half.

This plan is by no means recommended for general adoption, as the puddle will have a tendency to draw away from the eastern end of the trench, but it was resorted to in the present instance owing to the peculiar circumstances of the case, and that the eastern end of the trench has a tolerably flat slope.

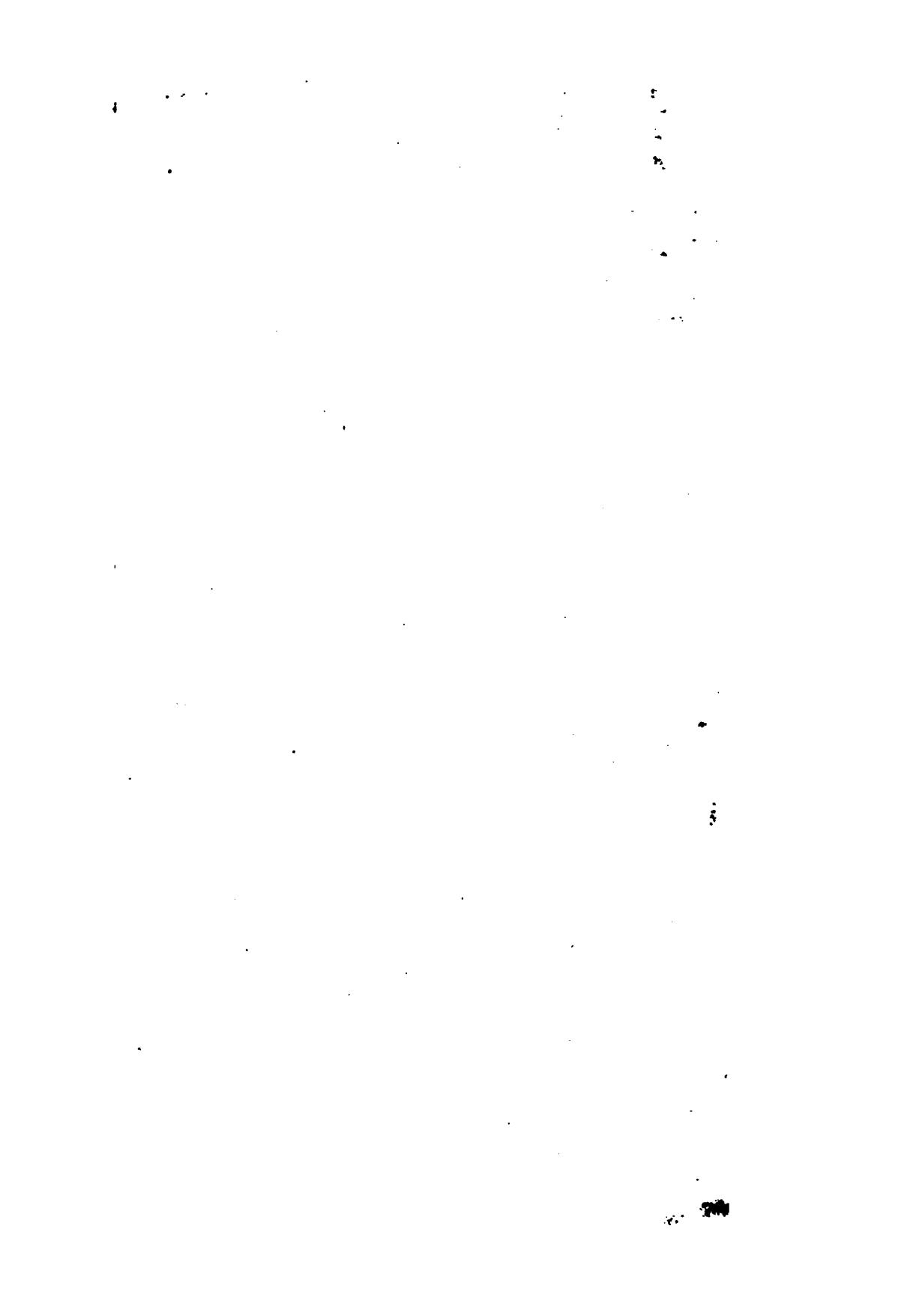
All the vertical faces of the rock will be done away with, and the bottom of the trench made to correspond with the dotted line on the longitudinal section.

The outlet of this reservoir is by means of the tunnel and valve shaft, shewn on the east end of plate 5, and alluded to on page 34.

The area of the reservoir is 12 acres, and it will hold over 50 million gallons.

Rainfall.

	Calculated Average Annual Rainfall in 3 Consecutive Dry Years.	Actual Average Annual Rainfall in 3 Consecutive Dry Years.	Years of Observation.
	Inches. 21.13	Inches. 20.46	1815 to 1867 (Inclusive)
	45.39	45.60	1843 to 1869 ,,
	36.61	40.43	1859 to 1869 ,,
	38.04	39.89	1849 to 1869 ,,
	66.54	52.71	1845 to 1866 ,,
	116.69	103.47	1845 to 1866 ,,
	48.78	44.61	1845 to 1866 ,,
	35.39	37.79	1855 to 1866 ,,
	37.61	40.40	1858 to 1866 ,,
	21.14	22.23	1855 to 1866 ,,
	22.00	22.14	1847 to 1866 ,,
	24.88	24.65	1847 to 1866 ,,
	20.61	20.21	1847 to 1866 ,,
	21.74	23.01	1850 to 1868 ,,
	25.76	26.13	1845 to 1868 ,,
	21.34	21.87	1850 to 1868 ,,
	33.77	35.00	1855 to 1869 ,, Year 1859 not recorded.
	29.95	34.82	1865 to 1869 ,,
	29.00	28.67	1855 to 1869 ,, Years 1859 & 1863 not recorded.
	21.46	22.67	1846 to 1866 ,,
	43.73	47.45	1861 to 1868 ,,
	36.26	35.91	



A

Do. f
Town all.

Bol

2,125

10

11

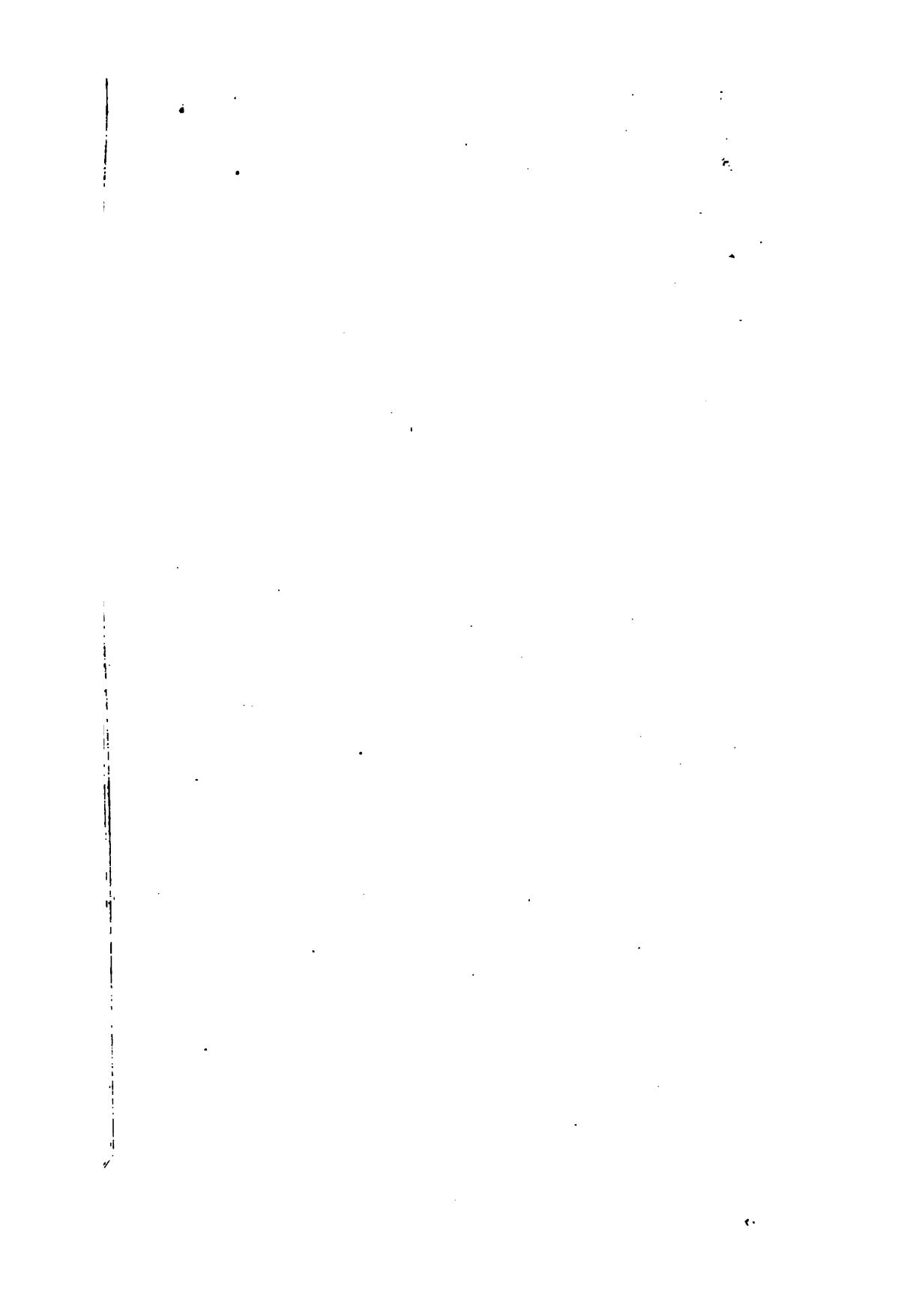
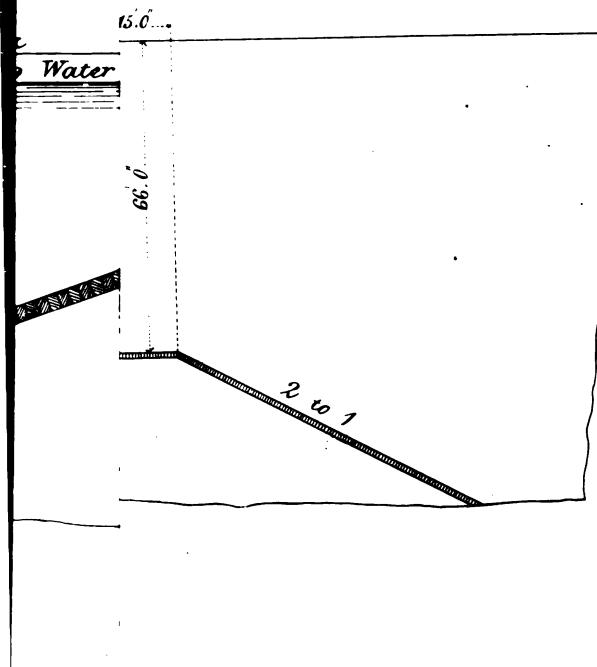


Plate 4

IV E



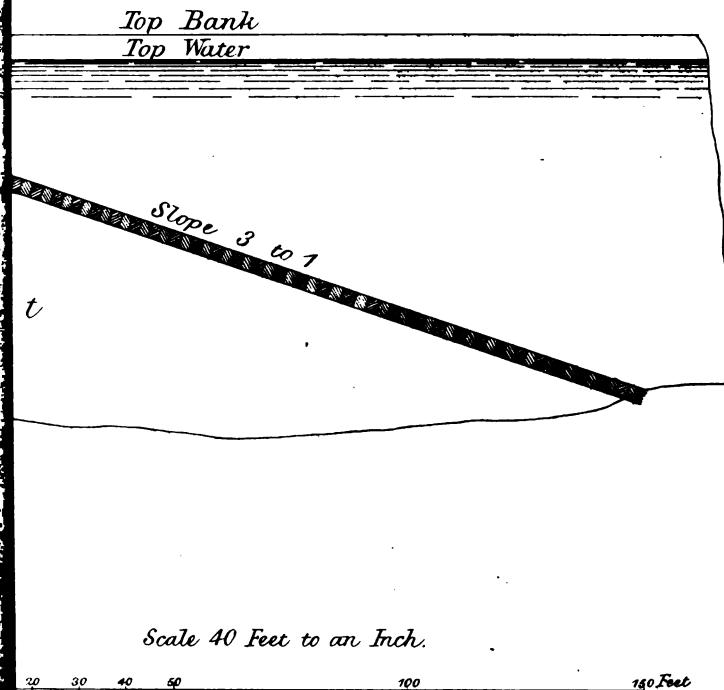
BAN *bet to an Inch.*

100 200 Feet

N° 7

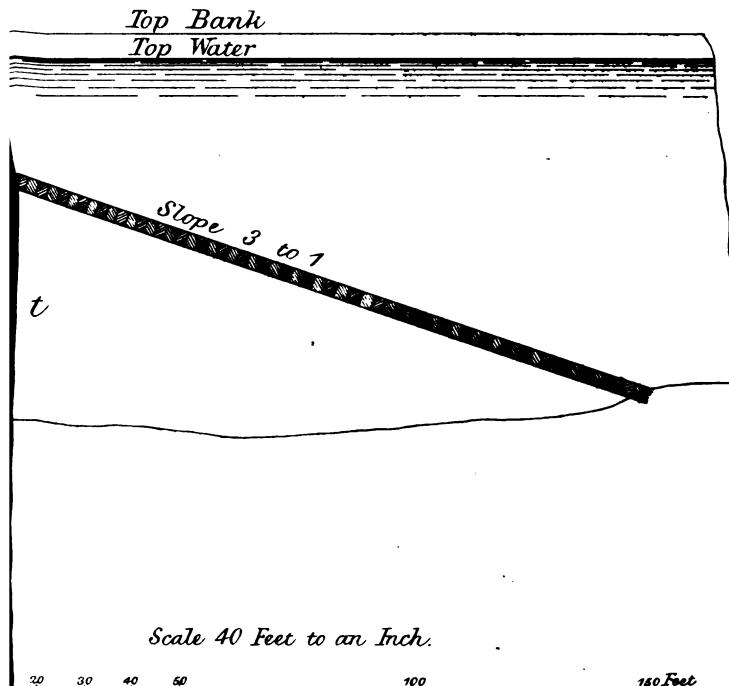
Hawley & C° Ltd. 43 Castle S' Holborn

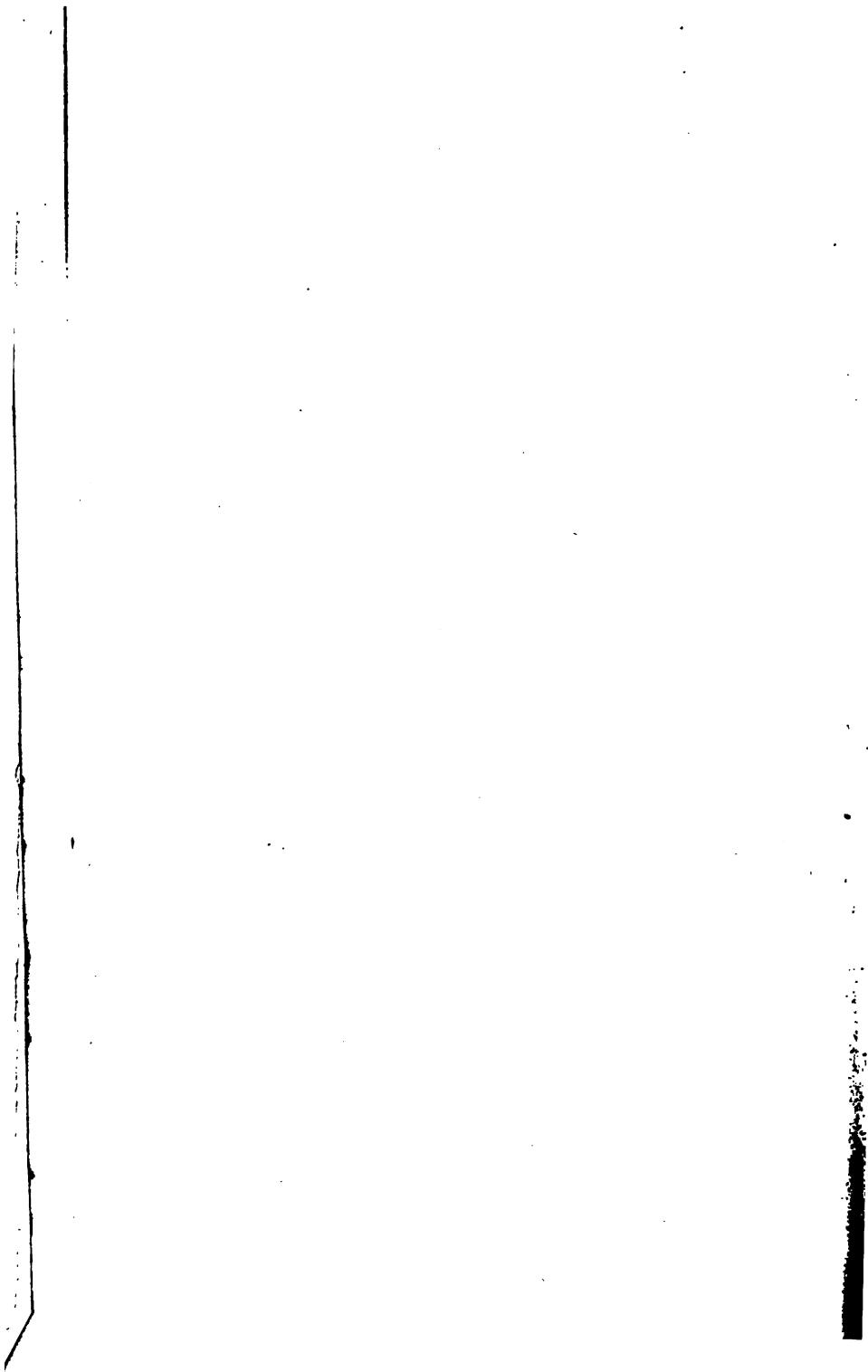
R WORKS.





R WORKS.





ERPO

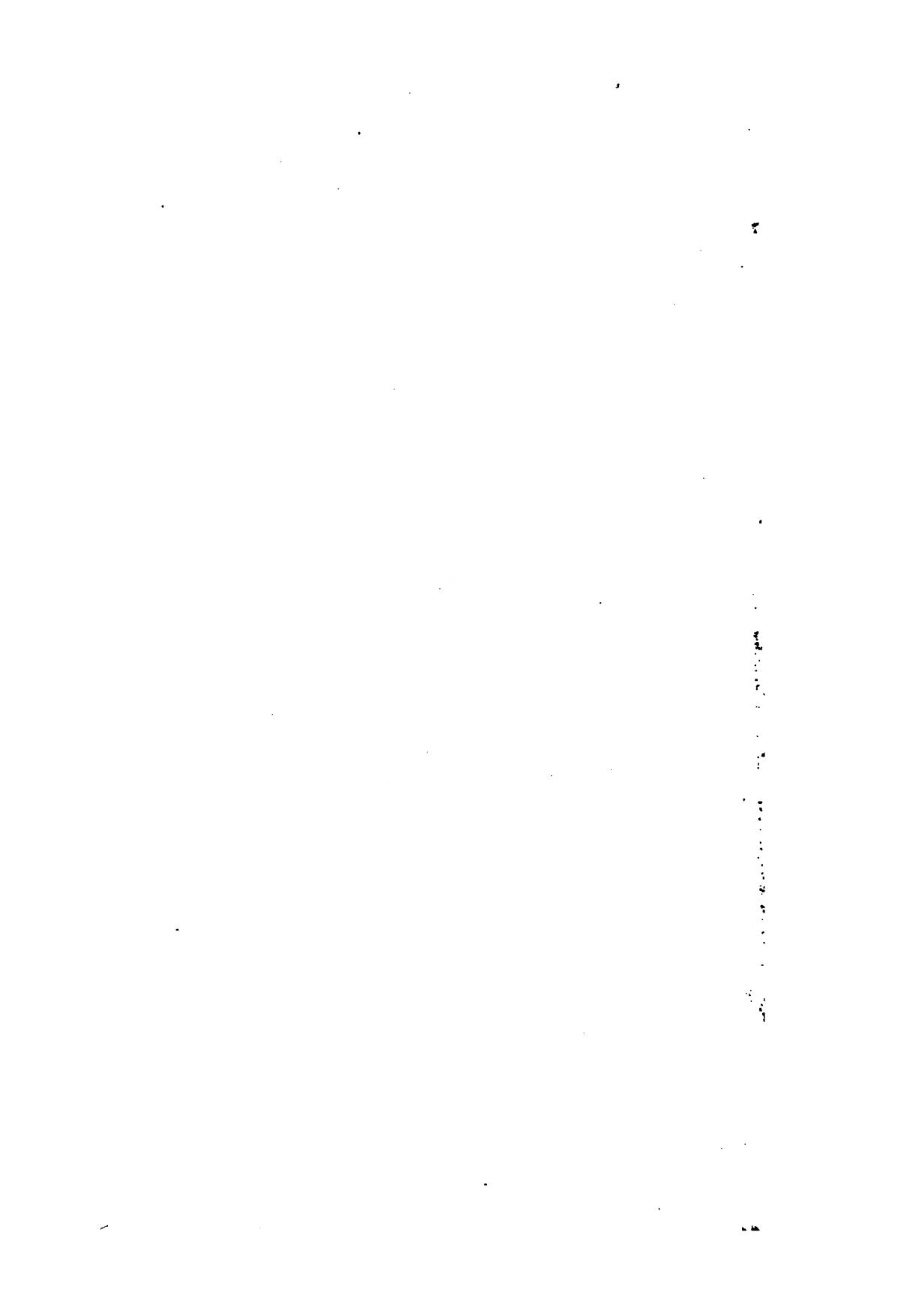
Emb.

Orig.

2 to 1

KMEN T an Inch.

200 Feet



R H Y

C R C



Foot n.

69

Just Published, medium 8vo, cloth, illustrated by a steel portrait, lithographs, and numerous wood engravings, including many accurate illustrations of Cornwall, its mines and mining machinery, Vol. I., 21s.

**THE LIFE OF RICHARD TREVITHICK,
INVENTOR OF THE HIGH-PRESSURE STEAM-ENGINE.**

By FRANCIS TREVITHICK, C.E.

(Vol. II. is in the Press, and will be ready in August next.)

Just Published, Second Edition, demy 8vo, cloth, with plates, 12s. 6d.

YACHTS AND YACHT BUILDING,

BEING A TREATISE ON THE CONSTRUCTION OF YACHTS, & MATTERS
RELATING TO YACHTING.

By P. R. MARETT.

In crown 8vo, cloth, 1s.

HOW TO PUBLISH A BOOK,

BEING DIRECTIONS AND HINTS TO AUTHORS.

By ERNEST SPON.

*Just published, crown 8vo, cloth, illustrated with forty-eight plates and
numerous wood engravings, 18s.*

ELEMENTARY PRINCIPLES OF CARPENTRY.

By THOMAS TREDGOLD.

REVISED FROM THE ORIGINAL EDITION, AND PARTLY RE-WRITTEN

BY JOHN THOMAS HURST, C.E.

Just published, in neat cloth case, 4s. 6d.

TABLES FOR SETTING OUT RAILWAY CURVES.

By CHARLES PULLAR HOGG, C.E.

Just published, demy 8vo, sewed, with Military Map of the Country, 1s. 6d.

**PRACTICAL LESSONS IN RECONNOITRING,
OUTPOST DUTY, &c.,**

SUGGESTED BY THE LATE AUTUMN MANŒUVRES.

No. I.—RECONNOISSANCE OF THE COUNTRY BETWEEN ALDESHOT AND WOOLMER.

LONDON : E. & F. N. SPON, 48, CHARING CROSS.

NEW YORK : 446, BROOME STREET.

Just published, Part I., Vol. I., in demy 8vo, sewed, with wood engravings, price 5s.

JOURNAL OF THE SOCIETY OF TELEGRAPH ENGINEERS,

INCLUDING ORIGINAL COMMUNICATIONS ON TELEGRAPHY AND
ELECTRICAL SCIENCE.

EDITED BY MAJOR FRANK BOLTON AND H. SCHUTZ WILSON.

Just published, 2nd edition, enlarged 64mo, roan, gilt edges, 1s.

SPONS' TABLES AND MEMORANDA FOR ENGINEERS AND OTHERS.

SELECTED AND ARRANGED BY J. T. HURST, C.E.

This work is arranged specially for the convenience of Travellers, Engineers, Architects, Surveyors, and Scientific Men generally; and is so small, measuring only $2\frac{1}{2}$ in. by 2 in. by $\frac{1}{4}$ in. thick, that it may be easily carried in the waistcoat pocket.

Now ready, demy 8vo, cloth, with plates, 7s. 6d.

HEALTH AND COMFORT IN HOUSE BUILDING; OR, VENTILATION WITH WARM AIR BY SELF-ACTING SUCTION POWER, WITH EXPERIMENTS.

BY J. DRYSDALE, M.D., AND J. W. HAYWARD, M.D.

Second Edition, with plates and wood engravings, crown 8vo, cloth, 7s. 6d.

THE COFFEE-PLANTER OF CEYLON.

BY WILLIAM SABONADIERE.

With an Appendix, containing various Extracts and Letters from other authority bearing on the same subject.

Now ready, demy 8vo, cloth, with plates, 5s.

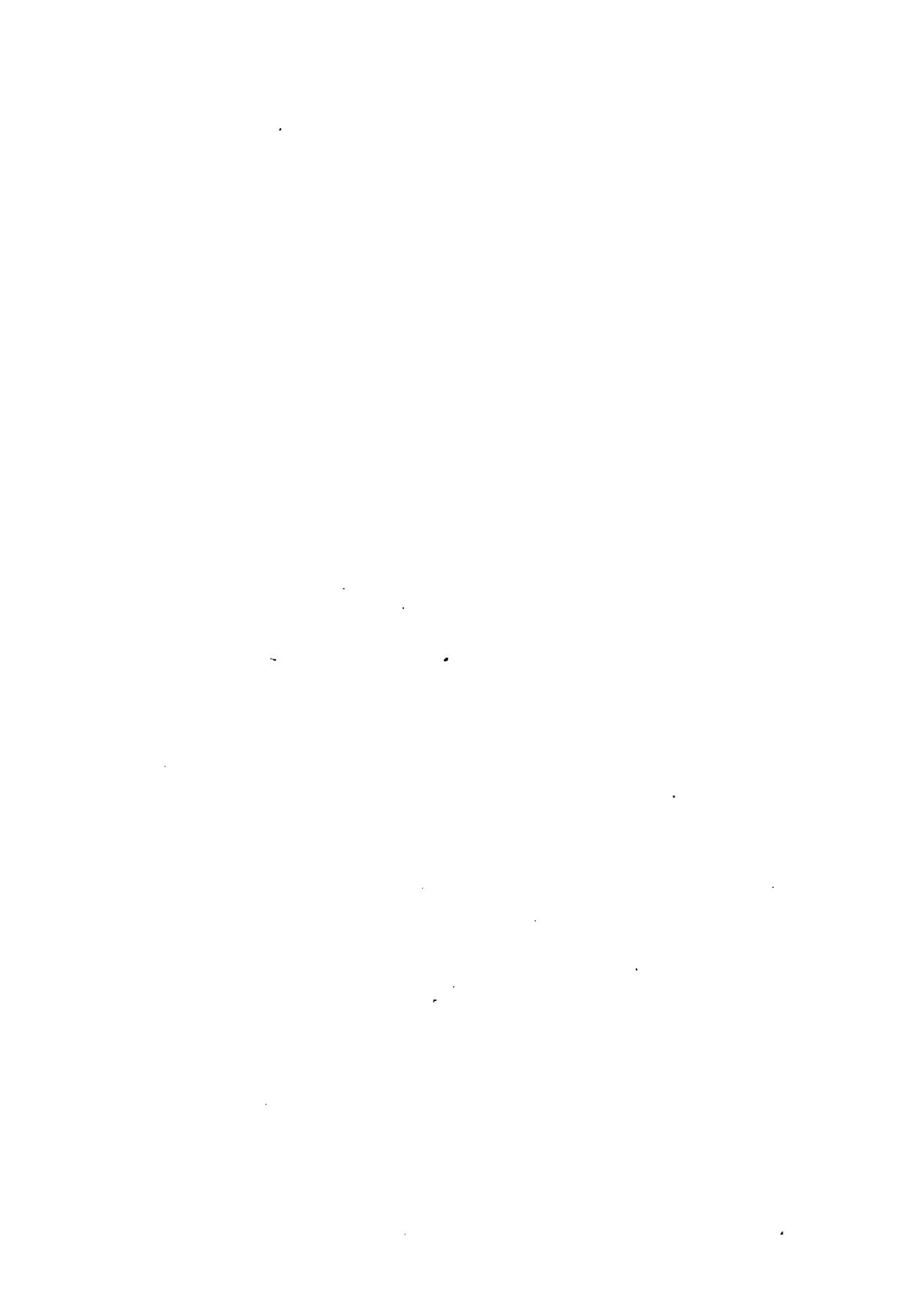
ON THE CONSTRUCTION OF CATCH-WATER RESERVOIRS

IN MOUNTAIN DISTRICTS, FOR THE SUPPLY OF TOWNS, OR OTHER
PURPOSES.

BY CHARLES H. BELOE, C.E.

LONDON: E. & F. N. SPON, 48, CHARING CROSS.

NEW YORK: 446, BROOME STREET.





CHARLES H. BELLOE
—
CATCH-WATER RESERVOIRS
OF
ON THE CONSTRUCTION